ARGON-38 ALPHA CAPTURE AND SUPERNOVA PRODUCTION OF ^{41}Ca.

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Introduction: Proper interpretation of the provenance of certain isotopic effects in meteoritic samples depends on comparison of data with the nuclear yields from astrophysical models. The reliability of those yields, in turn, depends on the validity of the input parameters going into the models. For example, estimates of nuclear yields from supernovae depend on hundreds or thousands of nuclear reaction rates, many of which are not determined experimentally. In this work, we present results of an experimental study of alpha-capture reaction rates on ^{38}Ar and explore the implications for production of the short-lived radioactivity ^{41}Ca. These rates were previously measured [1], but only at one angle (with assumed isotropy) and the data showed large error bars. New low-energy experimental techniques are enabling more accurate reaction rate measurements.

Methods: The measurements were carried out at the ATLAS facility at Argonne National Laboratory. A 133 MeV ^{38}Ar beam was delivered to a multi sampling ionization chamber (MUSIC) detector filled with 370 Torr of ^{4}He gas. As the beam particles travel through the chamber volume, they ionize the gas molecules. The resulting electrons drift through the Frisch grid in the detector towards the anode which is divided into 18 strips. Strips 1-16 are further subdivided into two (left and right) asymmetric segments which allow identification of traces corresponding to the ^{38}Ar(a,n) and ^{38}Ar(a,p) reactions along with the elastic and inelastic scattering events. The experiment was performed in inverse kinematics with typical beam intensities of 5000 particles/sec. The beam intensity was reduced using a series of pepper pot attenuators along with ATLAS beam sweeper which increased the pulse period of the beam from 82 ns to 41 µs. The measured cross section as a function of energy was converted into a Maxwellian-averaged cross section appropriate for astrophysical nuclear reaction network calculations.

We explored the implications of the new cross sections for production of ^{41}Ca in supernovae with a simple type II supernova model [2]. We sent a 1.0 x 10^{51} erg shock through an initially 25 solar mass presupernova star model [3] and followed the nucleosynthesis in all the ejected zones. Our first calculation used the Reaclib V2.0 snapshot reaction rate library from http://jinaweb.org. The default ^{38}Ar(a,p)^{41}K and ^{38}Ar(a,n)^{41}Ca rates in this version of the library are from Sevior and collaborators [1]. Our second calculation used the rates determined from our recent measurement. We followed up the calculation in all zones with detailed single-zone calculations of zones showing differences in the ^{41}Ca between the different ^{38}Ar alpha-capture rates.

Results: When we use our newly measured rates, we find a ~25-50% increase in the production of ^{41}Ca in the supernova model compared to the case where we use the default Reaclib V2.0 rates. This increase shows up in several regions in the star. First, there is an increase in the inner oxygen-rich layers where the bulk of the ^{41}Ca is made during explosive carbon and oxygen burning. Second there is an increase in the layers near the helium shell. The reason for the increase in the production of ^{41}Ca is that the newly measured rates are smaller than the default rates. In particular, the ^{38}Ar(a,n)^{41}Ca rate is ~50% smaller over the temperature range of interest than the previous rate. This translates to a similarly ~50% smaller rate for the reverse reaction ^{41}Ca(n,a)^{38}Ar. Since this reverse reaction is the primary destruction channel for ^{41}Ca during explosive nucleosynthesis in the zones of interest, a decrease in the rate corresponds to an increase in the surviving abundance of ^{41}Ca.

Discussion: Our results show the range of uncertainty one would expect in the estimate of the explosive nucleosynthesis yield of ^{41}Ca from a key destruction reaction. While other isotopes and reactions will have their own dependencies, the results here are probably fairly representative of the overall astrophysical yield uncertainties one can expect from uncertainties in nuclear physics input.

It is worth noting that our calculations only address the effects of the newly measured rates on the explosive nucleosynthesis. One might also expect an increase in the pre-supernova production of ^{41}Ca due to the smaller ^{41}Ca(n,a) reaction rate. We are carrying out multi-zone nucleosythesis calculations to study this issue.

References: [1] Sevior M. E. et al. (1986) Nucl. Phys. A 454:128-142. [2] Bojazi M. J. and Meyer B. S. (2014) *Phys. Rev. C* 89:025807. [3] Rauscher T. et al. (2002) *Astrophys. J.,* 576:323-348.